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Review of development from GSHP to UTES in China and other countries

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A B S T R A C T

Energy storage technologies (EST) facilitate the efficient utilization of renewable energy sources and energy conservation, and they are expected to be more prevalent in the future. There is a great potential to substitute the use of EST for burning of fossil fuels by using stored heat that would otherwise be wasted and using renewable generation resources. These energy sources can be used more effectively through the addition of short- or long-term energy storage, even to the seasonal thermal energy storage. Underground thermal energy storage (UTES) is one form of EST, and perhaps the most frequently used storage technology in North America and Europe. Gradually it is growing as the application of ground source heat pump (GSHP) with UTES in China. But UTES systems involve complicated unsteady processes that include energy rejection, accumulation, preservation and extraction. This paper reviewed the progress of UTES companioning with GSHP worldwide, and surveyed the development of GSHP and the origination of UTES, especially as to soil/rock UTES. Meanwhile, the basic proposal for development in the future to supply a gap in the field of UTES in China was presented. A coming work should aim to more researching basic problems during the demonstration application, such as investigation of mechanisms, characteristics and performance of the unsteady and transient heat transfer in a complex underground environment, and control strategies of the UTES system. These problems will strengthen theoretical and practical understanding and facilitate more extensive application of UTES in China.

Contents

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1. Introduction

Energy storage technologies (EST) are of strategic and necessary measure for the efficient utilization of renewable energy and energy conservation. EST can technically substitute the fossil fuels by using stored heat or cold that would otherwise be wasted or by using renewable energy resources. These energy resources can be used more effectively with short- and long-term energy storage, and seasonal thermal energy storage. Thermal energy storage (TES) systems enable greater and more efficient using of these fluctuating energy resources by matching the energy supply with demand, for example using the heat energy in winter that stored in summer. By contributing to large-scale energy efficiency, energy storage significantly reduces environmental impacts from energy activities, increases the potential uptake of some renewable energy technologies, increases the potential of sustainable energy development and subsequently leads to better energy security.

Fossil fuel dominant energy situation in China gives a rise to economic, political, and environmental concerns same as the majority of countries. The gap between production and consumption of energy is growing rapidly. China becomes more and more dependent on expensive imported energy resources, especially to petroleum and nature gas. Therefore, new energy resources must be explored to alleviate this condition, while energy conserving technologies are as important as exploring new resources. As pointed out by Sanner et al. [1] and Andersson et al. [2], the best way of energy conserving is to use the energy around us, which may be the natural resources like thermal energy in air, water and ground, solar, wind, biomass energy, fuel cell and waste heat from any mechanical, chemical and thermal process. As we known, the most aspects of underground thermal energy storage (UTES) technology are companioning with the progress of ground source heat pump (GSHP) in the field of using earth energy.

China is one of the most populous countries and the second largest energy consumer. Rising energy demand and import has made China a significant factor in the world energy market. The statistic from literature [3–6] indicated the Chinese energy situation as following.

Chinese rapidly growing economy will drive energy demand growth of about 7–15% annually (compared with growth of about 1% in the industrialized countries), as shown in Fig. 1. China currently consumes about 10% of the world's energy, which accounts for about 10% of world energy production.

China has been a net importer of oil since 1990s and is considered to become increasingly dependent on imports. However, it is expected to remain a net exporter of coal in the near future. In the past decade, Chinese energy import in 2000 totaled 143.34 million tons standard coal (MTSC) equivalent, only an increase of 130.24 tons over 1990. But from the start of new century, Chinese imports of crude oil, coal and natural gas in 2006 totaled 297.90 MTSC equivalently, an increase of 107.8% over 2000 and up 15.4% annually on average, as shown in Fig. 2.

The latest data indicated that the whole imported energy amounted to 334.54 MTSC, accounting for 12.60% of the aggregate energy of 2654.80 million tons in 2007, while accounting for 12.08% and 12.11%, respectively in 2005 and 2006. Serious shortage of energy resources has caused China to depend heavily on energy imports. Crude oil import in China reached 163 million tons in 2007, rising 12.3% year-on-year, accounting for about 80% of the total imported.

One new country's energy consumption and pollution reduction targets started in 2006 [7]. The 11th five-year plan for the national development (2006–2010) has set a goal of reducing energy consumption per unit of gross domestic product (GDP) by 20% in 2010. The sustainable development is impossible without sustainable energy. China, once the fastest growing yet most coal-dependent economy, is taking steps to develop energy-efficient and renewable energy. In the last 2 years, China has implemented a series of ambitious clean energy policies that will help to dramatically reduce the growth of the country's energy consumption and greenhouse gas emissions.

The Renewable Energy Law (RE Law), took into effect since 1 January 2006, has set the most active aggressive and legally binding target. By 2020, 15% of all energy is to come from renewable energy, including wind energy, solar energy, water energy, biomass energy, geothermal energy, ocean energy, etc. The geothermal energy among renewable energy involves pure

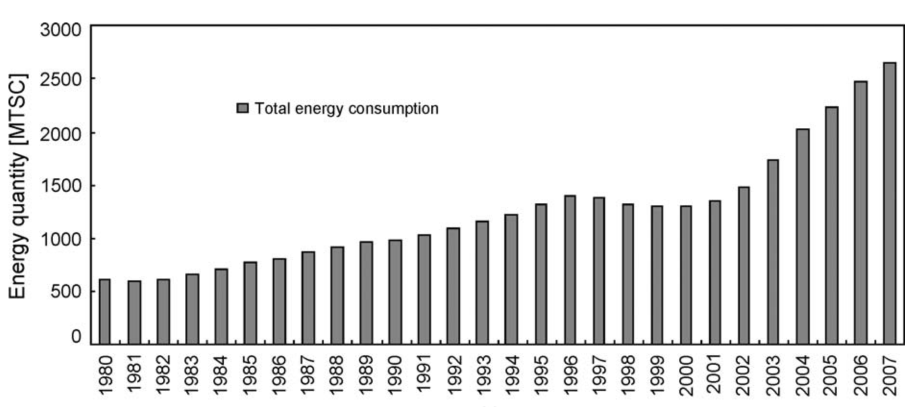

Fig. 1. Annually energy consumption in China.

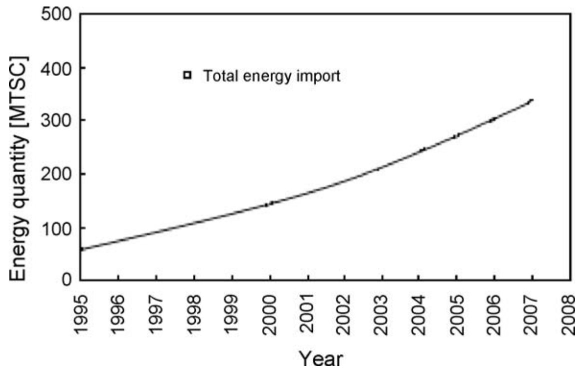

Fig. 2. Annually total energy imported in China.

geothermal heat and also earth energy (from soil, groundwater, surface water, etc.) In August 2007, Chinese National Development and Reform Commission (NDRC) launched its medium- to long-term renewable energy development plan. By 2020, installed capacity of small hydro, wind, biomass, and solar will reach 75, 30, 30 and 1.8 GW, respectively. The whole investment estimated to be about US $270 billion and has yet established a national renewable energy platform [8,9].

Building energy consumption has increased over 10% each year for the last 20 years and now represents 25–40% of all energy consumed in China. To improve energy conservation, national building codes for residential and commercial buildings have been adopted and demonstrations have been set up in some cities. Government has called for a 65% energy-saving building target for buildings in major Chinese cities, and now in more cities since 1 January 2008 [10].

Obviously, if a type of efficient seasonal utilization of solar energy can be combined with the underground thermal energy storage for the use of GSHP and it will be a green way of building energy.

2. Basic type of UTES

EST systems can not only reduce the time mismatch between the supply and the demand of energy resources (i.e. solar energy, peak-shaving electricity), but also enable the use of natural ambient energy. Storing energy can compensate a temporary imbalance between supply and demand or alleviate it greatly. Thermal storage for short term (<1 week) is implemented most, such as ice storage and phase change materials (PCM). In contrast, the application of seasonal storage, a longer term (>3 months) is currently much less common, but growing in its application worldwide. UTES is one form of EST and it can keep a longer term and even seasonal thermal energy storage. Perhaps in the present, it becomes the most frequently used storage technology in North America and Europe. In the past 20 years, much more applications of UTES have been studied and implemented. As to now, there are two types of UTES, aquifer thermal energy storage (ATES) and soil/rock UTES or borehole thermal energy storage (BTES). The former is similar to the geothermal groundwater system which involves storage and provides for both heating and cooling on a seasonal basis, and the latter is similar to the geothermal soil/rock system which also involves storage and provides for both heating and cooling on a seasonal basis. Both types of storage systems offer maximal energy storage over others and much higher energy savings over direct use systems. The environmental benefits of using UTES are very obvious. UTES systems are very important for the cleaner future.

2.1. Aquifer thermal energy storage

ATES uses underground water that called as aquifers. There are two wells (typically) on either side with hydraulic coupling. One well is for the warm water and the other one is for the cold. In winter, warm water is cooled and passed to the cold well. Energy is extracted by the heat exchanger for heating purposes. In summer, the process is reversed and cold water is used for cooling. The advantage about this system is that it is environmentally safe; the water which circulates from underground to the heat exchangers and back cannot be contaminated as it always remains in the system. Moreover, there is no net loss of water from underground. The only problem is that this system must be used in areas that are above aquifers. Actually, we must pay more attention to risks of the leak contamination and the damage of geological structure.

Applications of ATES in large-scale projects started in the 1960s, mostly in China. By 1984, there had been 492 cold storage wells, supplying cold thermal energy to the industries to cool down the machinery. Recently it is fewer and fewer. The bottleneck of ATES is recharging which is the key point of groundwater resource sustainable utilization. Low-temperature ATES and heat pump technology should be combined to improve efficiency and extend development space [11].

In Sweden, updated statistics number of ATES plants until January, 2003 is 38 [2]. Andersson et al. [2] reviewed that survey within Annex 13 of IEA ECES IA revealed that 40% of the plants have had or have operational problems or failures. The major part of these has been solved by fairly simple measures. However, approximately 15% have encountered difficulties of well capacities. The dominating reason is the clogging of the wells caused by iron precipitation. Certainly, this technique reduces the fossil fuel consumption. In general, negative side effects, if any, are negligible to some extent compared to the fossil fuels.

2.2. Soil/rock UTES (or BTES)

Soil/rock UTES is very different and more complex than ATES. In all of types of soil/rock UTES, BTES is a typical one, mostly used. In the BTES system, holes, typically 50–200 m in depth, are drilled into the ground for heat exchangers. Heat exchangers are plastic tubes that contain heat carrier fluids to carry the thermal energy from the earth and back to the surface for usage. Usually the heat carrier fluid is water or anti-freeze. The efficiency of BTES systems depends on many factors such as the ground temperature, operational temperature of the storage, groundwater flow condition, thermal properties of the ground, etc.

A larger-scale application of BTES is in Luleå, Sweden. The system has 120 holes which are 60-m deep. It is used to store warm thermal energy at about 70 °C which can be used to heat the local university. At the moment, the largest BTES is in Fort Polk, United States. There are 8000 holes, which supply both cold and warm thermal energy to residents. BTES are also used to thaw the frozen roads in Japan, Switzerland and USA [12].

Strictly, the research of soil/rock UTES started from the last decade and has been developed a little in China, but there are no enough practical applications and further fundamental work. Therefore, fundamental research and practical application will be important in worldwide.

3. Overseas technology status in GSHP and UTES

3.1. Overview

UTES as one form of EST, is widely used in Europe and North America, and expected to be more and more prevalent in the

future. Literature [13–17], respectively made a summary and survey for the current status and situation of UTES. UTES applications have slowly gained acceptance in the world energy market. Two UTES concepts are successfully implemented: ATES and BTES systems. However, there is still a certain risk for operational problems that might jeopardize the calculated profit. From a legislation point of view, any ATES application needs a permit, because there is a problem of underground water protection. BTES and other soil/rock UTES systems are normally used in smaller applications. It gradually gets more and more acceptable. The majority of these are applied in space cooling of commercial or institutional buildings and in process cooling. From a technical point of view, BTES is much simpler to construct and operate than ATES. Furthermore, they can be applied in almost any kind of geology. Another advantage compared to ATES is that the permitting procedure is much simpler and theoretically it almost never damages the underground water and geological stratum structure. The major market obstacle is that the profitability is not always acceptable if calculated as a straight payback time. To increase the market potential, it is necessary to further R&D on improvement of borehole heat exchangers (BHEs), and on more effective operation control.

It is important to further investigate the special phenomenon, behaviors and mechanism of underground heat transfer process in storing heat and cold. As we known, a soil/rock UTES system involves complicated unsteady and transient processes that involve energy rejection, accumulation, preservation and extraction, especially in a field of multi-borehole. In fact, the UTES has been developing as the GSHP. The GSHP system with combined heating and cooling can facilitate heat/cold thermal energy storage at the same time. Instead, the cooling capacity relies on the waste cold that has been accumulated in the earth during the heating season. When the cold energy is extracted as direct cooling during the summer, the energy factor will be about 20–30 [2].

As been reviewed by above literatures, in recent years BTES has become a preferred or alternative system for cooling and heating of special building and process in some countries of Europe. The typical heating and cooling capacity is 50–250 kW by 10–50 boreholes drilled to a depth of 100–200 m. The applications are mostly for commercial buildings (offices, hotels, supermarkets, schools, snow melting, etc.). It is predicted that the market potential is tremendous. Approximately 20,000 new GSHPs are installed each year and these can quite simply be designed as small-scale BTES applications. In addition, the older GSHPs can in many cases be converted to utilize direct cooling in summer. As a matter of fact, the most common hesitation for BTES utilizations is that the profitability is on the edge of being acceptable. The first cost and operating cost are some important worries. Additionally, before we know more about the risks, such as contamination of groundwater due to the leak of anti-freeze, abnormality of earth temperature, earth wound of more and more deep hole filling plastic pipes and other environment impacts and technological problems, a large-scale BTES will encounter numerous obstacles and difficulties. However, there is a tendency that the customer's value, the long-term environmental benefits and the sustainable renewable energy conversion benefits more and more, and also consider the long technical life of the boreholes and the low maintenance cost into the final calculation and design. Undoubtedly, the imbalance of heating load and cooling load need the UTES have energy supplement.

In fact, the climate in the northeast of China is similar to that of Sweden, so we can take their demonstrations as a reference example. As we known, in solving the issue of imbalance of heating/cooling load, now northern Europe has become a representative of the practical BTES utilization, and these countries have done a lot of R&D work. In many countries, namely Sweden, Switzerland, Austria, Denmark, Norway, Poland, Turkey, Germany, France, USA, Canada, Japan and China there are a large number of GSHPs in operation. This will facilitate the utilization of UTES.

The Implementing Agreement on Energy Conservation through Energy Storage (ECES) was established in 1978 by International Energy Agency (IEA) with the objective to facilitate international cooperation on research, development and demonstration (RD&D) of new, innovative energy storage technologies [13,17]. By now, with more than 20 implementing agreements, IEA has done much more achievements to facilitate the research, development, implementation and integration of energy storage technologies that optimize energy utilization by improving overall energy efficiency and economic growth, while benefiting the local and global environments. Fortunately, China has begun to take part in some activities on ECES-IA, and Tsinghua University has been invited to join the ECES as a sponsor. In April 2007, 63rd ECES Executive Committee meeting was held in Beijing, China.

Especially, American Brookhaven National Laboratory, Oak Ridge National Laboratory, National Renewable Energy Laboratory, Oklahoma State University and Alabama University, Sweden Luleå University of Technology and Lund University, Turkey Cukurova University, Canada Ontario University, Poland Warsaw University of Technology and Cracow University of Technology, Germany Justus Liebig University, Japan Kyoto University and Yamagata University and other overseas organizations performed more researches on in situ testing of thermal properties, thermal response tests (TRT), simulation calculation of model, borehole construction, grouting of GHEs, GSHE and BTES, thus make it possible to design GHEs systems with accurate scale of holes, active depth and spacing. Their work has put a good platform for using UTES.

3.2. Typical implementing demonstrations

A large scale of industrial energy conservation with UTES, 40 boreholes and 200 m depth, from ITT Flygt Emmaboda in Sweden has been implemented [18]. By using UTES systems to store cold from winter to summer, free cooling can be provided the whole year around. These types of systems will not only save a considerable amount of electricity, but also increase the indoor comfort of the workshops. By using UTES for seasonal storage of heat, the waste heat can be more efficiently utilized within the industry. This system is estimated to cut the district heat supply with approx. 1500 MWh/year. In addition, it will annually supply free process and comfort cooling with 800 MWh. The performance factor for the heat and cold production has been estimated to be in the range of 10. However, the project in the first phase has been evaluated to be technically and economically feasible. The usage of waste heat for the building and renewable energy resources will contribute to a significant reduction of CO_2 as well as other environmentally harmful emissions such as SOx, NOx, CFC and different types of unhealthy solids.

It is reported that in Sweden, the long-term objective of seasonal storage is to store solar heat from the summer to the winter for space heating [19]. Seasonal heat storage is necessary if solar heat can provide any significant contribution to the annual heating demand and domestic hot water. A new residential area, Anneberg, 50 residential new houses, is constructed in Danderyd, the north part of Stockholm. The city encourages the utilization of renewable energy. This solar heat application is one of the 10 largest solar heating plants in Europe and the very first with borehole storage in rock. The solar plant and the seasonal borehole storage have been in operation since spring 2002. Roof integrates 2400 m^2 solar collectors and the store covers 70–80% of the yearly heating and domestic hot water demand. During the summer, part

of the collected heat is stored in a borehole store with 100 boreholes drilled in bedrock to 65-m depth. Groundwater-filled boreholes are fitted with double U-tubes as ground heat exchangers. The system includes low-temperature space floor heating and individual electrical heaters for peak and supplementary heating.

In Turkey, Cukurova University's researchers investigate the availability of cold for injection with BTES [20]. The BTES can use renewable energy sources like winter air, surface water, etc. for cold injection. Cold extraction from winter air and injection into the ground with BTES was performed in 2002 and 2003. Their work presents experimental investigation of the availability. Results show that cold injection with BTES by using winter air in this region is also possible. It is of great importance to make UTES systems widely used around world, especially in developing countries because of their environmental and economic benefits.

American Brookhaven National Laboratory cooperated with Alabama University to seek optimal performance of closed-loop GEHs in the backfill of BHEs, which is dependent upon the thermal properties of the backfill in the annular region between tubes and the outer bore wall [21]. Equally important is the protection of groundwater aquifers from contaminants that may flow from the surface or other aquifers through poorly sealed boreholes. Conventional cement and bentonite-based grouts have relatively lower thermal conductivities. They reported the results of four mixes of thermally enhanced cementitious grouts. Results indicated that the cement grouts which are enhanced with low-cost additives have thermal conductivities three to four times of conventional high-solids bentonite grouts. Meanwhile, Germany Justus Liebig University Sanner et al. [1] also researched thermal enhanced grouts and the reduction of borehole thermal resistance [22]. It is clear that grouting is a very important technique of GHEs in both GSHP and BTES.

In Japan, Kumamoto University, Kyushyu Electric Power Company Inc. and Fujita Corporation combined to investigate how much the peak daytime demand for electricity is reduced by an UTES system that uses surplus electricity during the night time [23]. In research, they reported a numerical simulation method and the results from an energy performance simulation of this system at Park Dome Kumamoto, a Kumamoto prefecture indoor athletic facility. The simulation results were in good agreement with the measurements, and showed that this simulation method was applicable for the prediction and optimization of an underground heat storage system for other conditions. It proved that this system could be very effectively applied in real architectural projects and contributed in alleviating cooling loads in Kumamoto.

An innovative largest scale BTES system in Canada, was established at The University of Ontario Institute of Technology (UOIT) [24]. 384 boreholes, each 213-m deep, would provide the basis for a highly efficient and environmental friendly heating and cooling system, capable of regulating eight of the university's new buildings. Under the lead of Dr. Rosen who has carried out extensive research for over two decades on the TES, the UOIT borehole thermal energy storage system was completed in 2004. Now the thermal storage system is a critical component of the university's heating and cooling system, and helps to keep the cost down and the efficiency up. In addition, the thermal storage system is used for research and to educate students in TES. Researchers and students have the rich opportunity of on-site research and education in one of North America's biggest geothermal fields.

3.3. Relevant theoretical works

In fact, in the investigation of GSHP and UTES, experiments always coexist with the numerical calculation. Modeling and calculating for simulation are important tools in design and prediction. In the world, researchers have taken much more simulations on GSHP and BTES and their works promote the development and make the progress, such as simulating the performance of a pavement heating system with closed-loop GSHP systems [25], mathematical models of heat transfer process in ground energy storage bin [26], modeling of vertical ground loop heat exchangers for GSHP system [27], simulation of intermittent ground temperature in recoverable process of GHEs [28], heat transfer model of GHEs in ground-coupled [29] and so on. As we known, the underground experiment is a very difficult task, so numerical analysis has been regarded as an effective way to simulate complex experiments and to save time and capitals. Numerical experiments can also extend the limitation of experiments and predict and design the system at any working condition. In the present study, in parallel with the experimental test, the heat transfer process in the field of GSHP and BTES is studied numerically by using a finite element method and some software.

As to the calculation of ground temperature and inlet/outlet temperature of GHEs, the most typical models published include the line source model, the cylindrical source model, and Eskilson's model [27]. All three models can describe the heat transfer of ground in buried tube. Generally, computational platforms dominantly related with some software, for example TRANSYS, HVACSIM+, ANSYS and other commercial software. It is important to understand how the temperature is distributed around the GHEs. In general, the performance of the GSHP system is relative to the ground temperature. If the distribution of ground temperature during the system operation is predicted, especially to inlet/outlet temperature of GHEs, the system can be more properly designed, and as a result, the borehole geometry and the number of the boreholes, so as the allocation and placement, can be optimized. Indeed, this will be also good for facilitating the GHEs, improving the COP (coefficient of performance), and reducing the initial capital investment.

Recently, some African countries began to pay attention to in the UTES. In the Libya, researchers of Sebha University have been studying the Soil UTES [30]. Experimental investigation on temperature distribution was conducted through the underground soil of Tripoli (Capital of Libya). The aim of the experiment is to monitor the temperature variation of the underground soil under a depth of 4 m and around the year, in order to know the thermal capacity ability of the soil to be used as a seasonal thermal storage.

4. Domestic development situation and relevant work of GSHP and UTES in China

4.1. Brief review of GSHP

In 1980s, some research institution started trying to do research on GSHP. Since 1996 some scholars and engineers visited America, Sweden, Germany, Canada, etc. to study the technology of GSHP. The first generation of Chinese FUERDA geothermal central air conditioning unit was installed in two residential buildings with the floor area of 50,000 m^2 in Liaoyang, Liaoning province in 1997. At the same time, China-US started technology cooperation in energy efficiency and GSHP was one of the most important field. Then three demonstrations were built up from the beginning of the 21st century. China started to show this technology with large pilot projects, especially in Shandong, Beijing, Liaoning, etc. Therefore, after the earliest research of GSHP in China began in 1980s, the GSHP technology not only became the hot research subject in heating and cooling building and supplying hot water but also applied to the engineering practice by the end of 1990s [31].

The market survey shows that there were 2537 demonstration engineering projects of GSHP up to 2005, about 20 million m^2 in the practical running, and Table 1 indicates the project quantity distribution in some provinces [32,33]. Nearly the principal areas of China were interested in the GSHP technology and intended to enter this new field in the future, such as Beijing, Tianjin, coastal and inland provinces, and even Xizang (Tibet), Xinjiang and Hainan.

Furthermore, these engineering projects contain various categories, for example office building, hotel, residential building, workshop building, school, villa house, hospital and emporium and their percentage follows as Fig. 3.

The coexistence of various kinds of GSHP was caused by the different climate zones in China, such as underground water HP, ground-coupled (or soil source) HP and surface water HP. Accordingly, we should make use of renewable energy in buildings based on different location and climatic zones. In a questionary of 88 typical projects, their percentage, respectively shows in Fig. 4.

(1) Underground water HP accounts for 45%in the total market;
(2) ground-coupled or soil source HP accounts about 35%;
(3) surface water HP accounts about 20%.

Underground water HP system started from 1995, and the products had been imported from Europe and the United States. Through strengthening the international collaboration, more demonstration projects were developed with the most widely application. The biggest single project floor area reached 186,000 m^2. According to investigations done by many researching organizations, the application of underground water HP system focused on Beijing, Liaoning, Hebei, Shandong province, etc.

Ground-coupled soil source HP system application is very complicated in the early period. Its procedure needs a strong theoretical, practical understanding and previous experience. Nevertheless in recent years it grows fast and the biggest single project floor area reached 160,000 m^2. An investigation shows that the application of GSHP focused on Beijing, Hubei, Jiangsu and some major area of China lacking water.

Table 1
Quantity of GSHP engineering projects (2005).

Province	Quantity
Beijing	758
Shanghai	129
Tianjun	154
Jiangshu	68
Hebei	303
Zhejiang	43
Shanxi	28
An-hui	24
Neimenggu	50
Fujian	20
Liaoning	147
Jiangxi	39
Jilin	57
Shandong	94
Heilingjiang	36
Taiwan	0
Henan	112
Guizhou	38
Hubei	58
Yunnan	2
Hunan	58
Shanxi (NW)	70
Guangdong	64
Ganshu	43
Qinghai	7
Guangxi	18
Hainan	1
Ningxia	36
Chongqing	13
Xinjiang	8
Sichuan	25
Xizang	34
Sum	2537

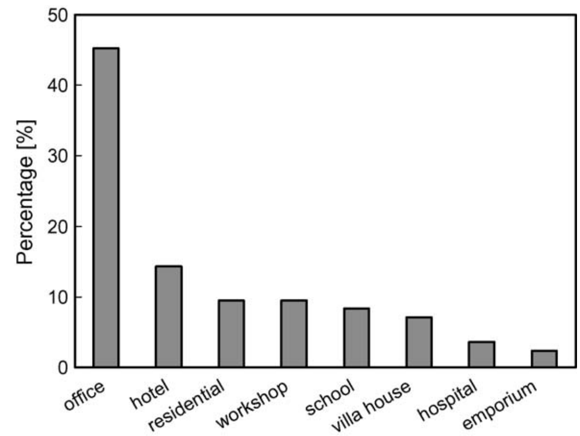

Fig. 3. Category percentage of GSHP in China.

Surface water HP system is used in the region where abound in water or other advantage conditions. There are larger city level demonstration projects, including lake, river, seacoast, sewage and industry waste water for the district heating in north of China and cooling in south of China.

The statistics [33] shows that from the perspective of areas in current projects, the projects with the floor area above 50,000 m^2 (50 T. m^2) account for about 16%, the projects with the floor area between 10,000 and 50,000 m^2 account for 42%, while those below 10,000 m^2 account for 42%, as shown in Fig. 5. Actually, the future growing potential of a large scale of GSHP is promising.

In 2006, the Ministry of Construction issued the Code "Technical Code for Ground Source Heat Pump System (GB50366-2005)". Subsequently the Ministry of Construction and Ministry of Finance together set a special financial support for the GSHP pilot projects over the nationwide.

4.2. Relative state law and policies

China Renewable Energy Law took into effect on 1 January 2006. The state encourages the application of solar energy and geothermal energy in the new buildings and the retrofit buildings. The "Building Energy Saving Management Regulations" issued in 2004. National Development and Reform Commission also issued the documentation "National Energy efficiency, mid-long term planning" to push the application of renewable energy in building. In August 2006, the State Council promulgated "Strengthening the energy efficiency work" and "China National program to Climate Change" to develop widely renewable energy and especially to support the development and application of wind energy, solar

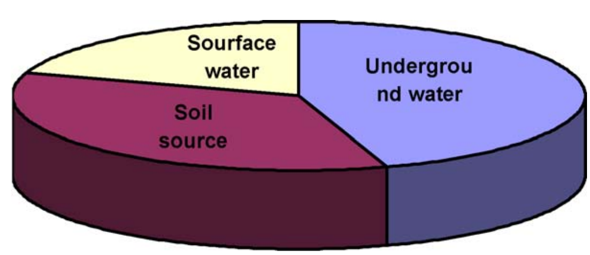

Fig. 4. GSHP markets distribution in China.

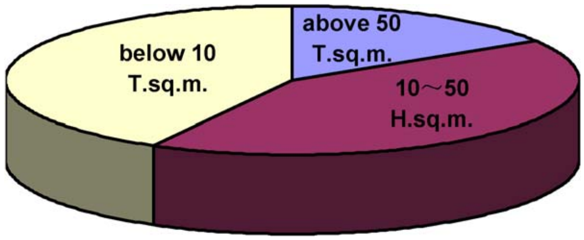

Fig. 5. Areas percentage of GSHP in China.

energy, geothermal energy, ocean energy, etc. and spread the technology of space heating and hot water supplying with geothermal energy [33].

In the last years, the Ministry of Construction and the Ministry of Finance jointly also issued much more documents, ''Opinions on Promoting Application of Renewable Energy in Buildings'', ''the Tentative Management Method of Renewable Energy Development Special Fund'' and ''The Assessment Method of the Renewable Energy Demonstration Projects'', which clearly support the promotion of the utilization of renewable energy in buildings.

Excitedly, there are eight key areas in a plan of ''Opinions on Promoting Application of Renewable Energy in Buildings'', four of which deal with GSHP [33].

(1) Using water source HP for heating and cooling in the regions where is rich in groundwater and surface water;
(2) using sea water HP system for heating and cooling in the coastal areas;
(3) using ground-coupled soil GSHP technology for heating and cooling;
(4) using sewage HP for heating and cooling.

China's first technical code for geothermal heat pump system engineering, ''Technical Code for Geothermal Heat Pump System Engineering (GB50366-2005)'', has been promulgated and took effect on 1 January 2006. The code plays a significant role for the development of geothermal heat pump industry. The code is composed of eight parts, including general principles, technical terms, engineering exploitation, buried pipeline heat exchange systems, groundwater heat exchange systems, surface water heat exchange systems, indoor systems, equipment operation and trial running, etc. [36].

Domestic and international experiences as well as relevant thematic studies and investigations have been taken into consideration during the course of formulating the code; emphasis has been given to ensure the leading standard of the code and the feasibility of operation.

The Ministry of Land and Resources is now drafting a ''Technical Code for Exploitation of Shallow Geothermal Energy'' to normalize and advance the scientific exploitation and rational utilization of shallow geothermal energy.

Previously, Promulgation and enforcement of ''Water-source heat pump (GB/T19409-2003)'', ''Design and construction on the cool/heat source station of GSHP(Atlas 06R115)'', ''Design Atlas on water-source heat pump'', etc. have been completed for applying in new construction, renovation and expansion of the industrial and residential buildings. Engineering drawings from design and atlas have been applied and tested in practice, relatively close to reality.

Much more technical-engineer books have been published for the recent decade, for example ''GSHP Engineering Manual (2001)'', ''Design of WLHP Air conditioning system (2004)'', ''Design and Application of GSHPs (2006)'', ''Design and Application of Ground Source Heat Pump System (2007)'' [33].

The importance of GSHP was recognized in many countries due to energy saving, high efficiency and environmentally friendly features. During recent decades GSHP has grown rapidly in the world, especially in Europe. In order to facilitate GSHP development in China, many research organizations and administration departments have organized a series of activities, meeting, training, exhibiting for the promotional purposes.

According to state laws, national regulations and policies, the local policies from more municipal governments enacted local actions and measures, and made a blueprint of development.

4.3. Typical incentive cities

4.3.1. Beijing

Beijing, capital of PR China, has been promoting the application of new and high technologies for energy supply consumption, so as to increase the energy efficiency and help itself to build into an energy-efficient, clean and beautiful international metropolis. In just over a decade, as the Chinese government looks toward achieving sustainable development goals, especially in light of the 2008 green Olympics, energy consumption policy is an important factor in promoting the use of GSHP technology.

Preferential pricing, tax benefits, and subsidies are all encouraged for the promotion of GSHP. Thus, the development of GSHP utilization depends on forward-looking government policies, and efforts to educate the public about the economical and environmental advantages of GSHP technology.

In 1997, China and American subscribed the agreement to develop GSHP system in China. According to the agreement, three demonstrating engineering projects were established in Beijing. After some projects were put into use, much data came from reality operation, which supplied foundation for designing and operating.

Since then, the Chinese market for GSHP has developed significantly. With continuous commercialization of the technology combined with Chinese and US government support, GSHP could significantly contribute to China's effort to move toward more sustainable development. Beijing became a representative district of fast development in the past decade and it has completed the GSHP engineering projects with the floor area about 11 million m^2 estimated up to now [34].

In May 2006, Beijing municipal government and Development and Reform commission published ''Guidance on the Development of Heat Pump in Beijing'' to encourage the development of heat pump involving underground water HP, soil source HP and wasted heat source HP. The planning blueprint is to reach a accumulative total 30 million m^2 in 2010 [35]. Fig. 6 shows the history status and projects of GSHP development in Beijing.

In fact, as of now Olympic projects exerted 34 renewable energy resources items for Olympic village and venues, there are 9

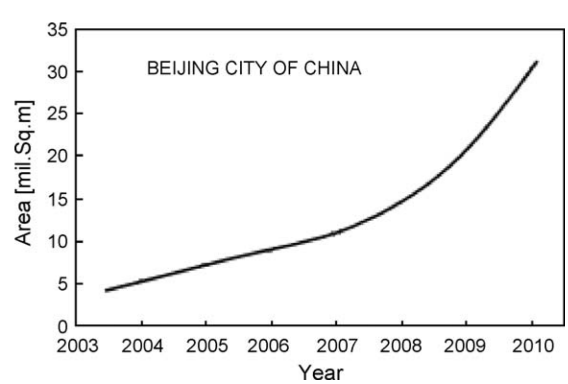

Fig. 6. GSHP developing in Beijing.

projects utilize ground source heat pump system. The floor area of Olympic buildings reached 450,000 m^2. For instance, in Olympic village, heat-pump system will save 15–20% electric energy compared with central air conditioners, annually saving 340,000 kW. And also 7 projects use solar photovoltaic technology; 10 projects apply solar-thermal technology [37].

With a building area of 80,890 m^2, the new National Indoor Stadium has a seating capacity of 18,000 people for the 2008 Beijing Olympics [38]. Taking full advantage of the energy at shallow ground, a GSHP system provides hot tap water, heating in winter and air-conditioning in summer for the stadium. The shallow ground maintains an almost constant temperature between 10 and 16 °C, the pump system can therefore draw energy from earth in winter, and release the heat in summer.

In Beijing University Gymnasium with 26900 m^2, two GSHP air-conditioning systems were installed on the first floor of the venue [39]. The underground pipes are located 75 m in the north and south sides of the building and the pump system can provide 188 kW/301 kW heating and 120 kW/192 kW cooling, respectively. The anti-freeze cooling water will be transported from these two circulating water pump units to the central air-conditioning system.

Further, the 2008 Beijing Olympic buildings combined the latest development of GSHP.

4.3.2. Shengyang

Shenyang, capital of Liaoning Province in the northeast of China, is the fastest one facilitating the utilization of GSHP in recent 2 years. This city was ever a famous old industrial base in China, and used to be a heavily polluted city. It has devoted great efforts to adjust its economic structure and bring environmental pollution under control since the launch of the old industrial base rejuvenation strategy in the northeast of China by the central government in the 9th and 10th five-year plan (1996–2005).

These years a total of 78.8 billion RMB has been invested into the implementation of over 460 key projects to reverse the city's environmental situation. In October 2006, Shenyang government issued acceleration documentation, ''Implementation work guidance on boosting the construction and application of GSHP''. The heat pump will become predominant heat supply pattern in Shenyang city in order to reform the traditional heat supply pattern and popularize GSHP technology to partly substitute for coal-firing heating. Shenyang takes full advantage of local resources advantages and vigorously pushes for the application and demonstration projects of ground, sewage, marine water-source and soil-source heat pump technologies.

In fact, the Liaoning province is a pioneer in the earliest application of GSHP in China. Precedent showed that GSHPs provided superior HVAC performance for many buildings, while offering improved efficiency and lower operating costs than conventional HVAC systems. Further, the districts had demonstrated significant reductions in most emissions from the local deployment of this technology. This has led the local government and some international organizations to join forces in a variety of efforts to facilitate the increased application of GSHP technologies.

Through recent years' development, its application areas have reached 18 million m^2 up to 2007. It is estimated that it can achieve the heat saving 318,800 tons of standard coal equivalent, emissions reducing carbon dioxide of 140,300 tons, reducing sulfur dioxide of 6400 tons, reducing soot of 4800 tons, reducing dust of 82,900 tons [40].

The municipal government of Shenyang has promised to implement preferential taxation and services policies to its districts for the expansion of application of GSHP. A planning goal is the application area will reach 65 million m^2. This plan will help save 1.625 million tons of standard coal equivalent, reduce 557,000 tons of carbon dioxide emission, reduce 26,500 tons of sulfur dioxide emission, and cut smoke and dust discharge by 20,400 tons a year by the end of the 11th five-year plan (2006–2010). Fig. 7 shows the status and trend of GSHP development in Shenyang [41].

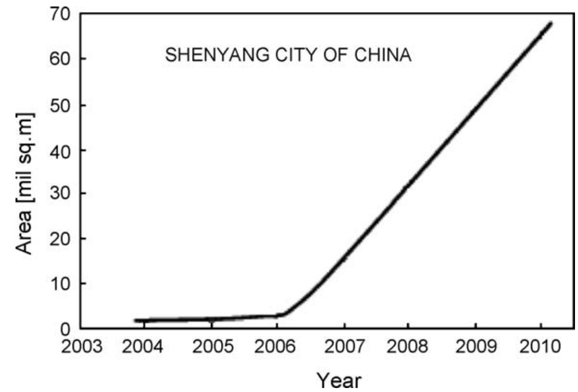

Fig. 7. Trend of GSHP developing in Shenyang.

4.4. Climate affect and necessity

The majority of China belongs to hot summer and cold winter climate area, and the weather condition needs good developing necessaries of UTES or BTES in using GSHP system. But the situation for the technology and good experience is worse than European countries, US, Japan, etc.

Due to its huge area, China was divided into five climatic zones from north to south in the thermal design and engineering, involving severe cold, cold, hot summer & cold winter, temperate, hot summer & warm winter [42]. In north areas, the main attention is heating, while in south, cooling. An absolutely large part of China is in need of both heating and cooling. The standard for climatic regionalization for building and civil engineering indicate the big imbalance between heating and cooling load in the hot summer and cold winter (HSCW) regions [43].

The coexistence of various kinds of GSHP was caused by the multiple climate zones in China. Accordingly, we should make use of renewable energy in buildings based on different location and climatic zones (Fig. 8).

Generally, in the extreme hot or cold climate area of China where are normally over 150 days in a year that demand cooling or heating. Therefore, GSHP has a good market competition. GSHP R&D and practical demonstration in China are also in the exploring and experimental stage and many issues also need to be investigated, especially to the enhanced heat transfer of GHEs and the mergence of UTES and GSHP.

Extreme climate makes the cooling and heating load imbalanced, but the climate and the imbalance of cooling and heating load have become a dominant reason of promotion of UTES in using GSHP systems. In China hot summer and cold winter zone covers 16 provinces and autonomous regions with 550 million of population [31]. In the hot areas, the south of China, summer is characterized by high temperature and solar radiant intensity. The mean temperature of the hottest month can be 25–30 °C and the relative humidity ratio can be about 80%. On the contrary, in the cold areas, both northeast and northwest of China, the mean temperature of the coldest month can be −10 to −20 °C and the relative humidity ratio only can be about 50%. The extreme hot and cold climate normally last over 3 months (as the values given in bold in Table 2). The mean temperature of some cities is shown in Table 2.

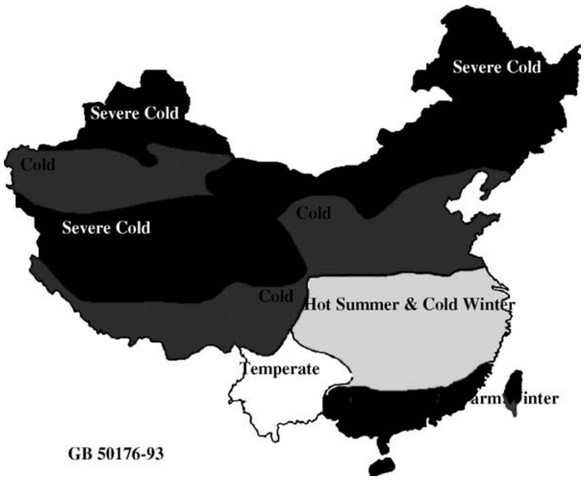

Fig. 8. Climatic zones for thermal engineering in China.

If the heat extracted from the ground annually is not equal to the heat rejected to it, the balance of earth energy will be difficult to be kept and the GSHP system cannot run steadily, thus cumulating energy-body, the earth cannot satisfy the energy demand for a long time. How to treat the energy balance between summer and winter and make operation reasonable is very important and critical.

Although there is a ground temperature recovery in transient seasons, the imbalance cannot be ignored. After long time running with a great deal of net heat reject/extract into/from the ground, the initial ground temperature field will change and energy equilibrium will be destroyed. Therefore, it is necessary to exploit the energy supplement system or hybrid energy system, and UTES is a better way. The energy supplement means the positive thermal energy storage and reaches an annual balance of the thermal energy source. The hybrid energy system means to combine more types of energy source, such as cooling tower, solar energy, waste energy and seasonal nature energy. Using hybrid energy system also can meet the need of peak load of a short term.

Therefore, the popularization of GSHP are obstructed and not developed in some extreme climate area of China. As we know, the UTES should be considered to take as an effective way which can supply and reuse the energy by storing energy in underground (soil and rock) seasonally.

4.5. Prophase work of soil UTES

GSHP with UTES systems are being installed more frequently for space heating and cooling and hot water in some European countries because of the rich technology and experience. Although there are some GSHP systems installed in China, very few have been integrated with the UTES systems, especially with soil/rock UTES or BTES. The application of soil GSHP systems proceeds with comparative slowness in China. Fortunately, at present more and more science and technology organizations have begun to pay more attention to the thermal energy storage and emphasized the need for the soil/rock UTES.

In 2005, the proposal for exploring the basic heat transfer mechanism and operational control on soil/rock UTES was offered firstly in China, and then National Natural Science Foundation of China (NSFC) approved this researching program to follow up the scent of the same international field and pursue the advanced achievements [44]. It is indicated that the investigation and exploration of the special technology of soil/rock UTES have been started.

In the past decade, some domestic universities and organizations have been addressing the R&D work of GSHP and some engineering projects have been completed. These works laid a foundation for the coming development of soil/rock UTES. We can see, much more completed basic researches and demonstrations of GSHP engineering take a very good role in further studying and applying soil/rock UTES, although only a few domestic literatures are available for dealing with soil/rock UTES or BTES directly.

To the author's knowledge, there are no practical soil/rock UTES systems in place in China. However, a few theoretic and experimental study was performed by some researchers [45–59], which indicated that such a system was practical using UTES. A computer simulation, based on the response factor technique, was developed for use in the design of a system and operational mechanism. The resulting algorithm was shown to be both computationally efficient and accurate. Every model established by individual researcher that should be appropriate for heat transfer process of GSHP and UTES, space heating and cooling studies was also developed. These modules may be integrated to compose an analytical system for the preliminary studies, performance prediction, design and operation simulation.

Based on the mathematic model of the soil cool charge and discharge system, the performance of integrated system and the influence of some factors on the heat transfer of the heat exchanger

Table 2
The mean temperature of some cities of China (°C).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Huhehaote	−**13.1**	−**9.0**	−0.3	7.9	15.3	20.1	21.9	20.1	13.8	6.5	−2.7	−**11.0**
Shenyang	−**12.0**	−**8.4**	0.1	9.3	16.9	21.5	24.6	23.5	17.2	9.4	0.0	−**8.5**
Changchun	−**16.4**	−**12.7**	−3.5	6.7	15.0	20.1	23.0	21.3	15.0	6.8	−3.8	−**12.8**
Haerbin	−**19.4**	−**15.4**	−4.8	6.0	14.3	20.0	22.8	21.1	14.4	5.6	−5.7	−**15.6**
Wulumuqi	−**14.9**	−**12.7**	−0.1	11.2	18.8	23.5	25.6	24.0	17.4	8.2	−1.9	−**11.7**
Shanghai	3.5	4.6	8.3	14.0	18.8	**23.3**	**27.8**	**27.7**	23.6	18.0	12.3	6.2
Nanjing	2.0	3.8	8.4	14.8	19.9	**24.5**	**28.0**	**27.8**	22.7	16.9	10.5	4.4
Hangzhou	3.8	5.1	9.3	15.4	20.0	**24.3**	**28.6**	**28.0**	23.3	17.7	12.1	6.3
Hefei	2.1	4.2	9.2	15.5	20.6	**25.0**	**28.3**	**28.0**	22.9	17.0	10.6	4.5
Fuzhou	10.5	10.7	13.4	18.1	22.1	**25.5**	**28.8**	**28.2**	26.0	21.7	17.5	13.1
Nanchang	5.0	6.4	10.9	17.1	21.8	**25.7**	**29.6**	**29.2**	24.8	19.1	13.1	7.5
Taibei	14.8	15.4	17.5	21.5	24.5	**26.6**	**28.6**	**28.3**	26.8	23.6	20.3	17.1
Wuhan	3.0	5.0	10.0	16.1	21.3	**25.7**	**28.8**	**28.3**	23.3	17.5	11.1	5.4
Changsha	4.7	6.2	10.9	16.8	21.6	**25.9**	**29.3**	**28.7**	24.2	18.5	12.5	7.1
Guangzhou	13.3	14.4	17.9	21.9	25.6	**27.2**	**28.4**	**28.1**	26.9	23.7	19.4	15.2
Nanjing	12.8	14.1	17.6	22.0	26.0	**27.4**	**28.3**	**27.8**	26.6	23.3	18.6	14.7
Haikou	17.2	18.2	21.6	24.9	27.4	**28.1**	**28.4**	**27.7**	26.8	24.8	21.8	18.7
Chengdu	5.5	7.5	12.1	17.0	20.9	**23.7**	**25.6**	**25.1**	21.2	16.8	11.9	7.3
Chongqing	7.2	8.9	13.2	18.0	21.8	**24.3**	**27.8**	**28.0**	22.8	18.2	13.3	8.6

with inner coil were investigated, such as coil material, soil type, charging temperature, fluid flux, coil spacing and moisture content of soil, etc. [45]. Some researchers established a two-dimensional model of earth thermal field to study the annual dynamic heat transfer characteristics of GHE, such as earth temperature distribution, depth, average heat transfer coefficient, and inlet/outlet temperature [46]. In the literature [47], the mathematical model of the thermal storage process in both solar and GSHP was set up. In the numerical calculation, the length of the exchanger pipe is divided into *M* parts in the longitudinal direction and the heat transfer in the every segment is added to obtain the total quantity of heat exchange of the whole pipe.

The recent research work was performed to analyze the performance of underground thermal storage in a solar-ground coupled heat pump system (SGCHPS) for residential building [48]. Based on the experimental results in the climate case of Tianjin, a big city near Beijing in China, the performance during a longer period was simulated by the unit modeling.

The design principle of closed-loop ATES system is studied. The single purpose and multi-purpose models of ATES system are established and optimized. The influence of different parameters on the economy and efficiency performances of the ATES system is analyzed [49].

In 1999, Jilin University of China started to investigate the ground energy for GSHP [50], and its researchers have been engaged in underground heat transfer of soil/rock for GSHP and UTES for decades [51–53]. In 2005, on the basis of previous researching works they tabled a proposal, "heat Transfer Mechanism and Time-rate Characteristic of Underground Thermal Energy Storage and Control" on soil/rock UTES to the NSFC, and begun to study the correlative basic theoretic problems in the field of soil/rock GSHP with UTES. They set up demonstration projects and took some experiments and numerical simulation analysis in the international cooperation with new energy and industrial technology development organization (NEDO) of Japan, Oklahoma state university of US, Nottingham university of UK, etc. [54–58].

However, the technology of GSHP system with UTES is in the stage of theoretical and experimental exploration and has many unsolved problems in theory and practice, so more work needs to do in China.

5. Typical trial of soil UTES in China

5.1. Function of different initial ground temperatures

As to the UTES, it actually implies the change of initial ground temperature due to a new energy accumulation. Therefore, it is important to focus on the variation of initial ground temperatures after the UTES process.

Therefore, to solve a problem of long term of running GSHP and reach reasonable temperature level and restoration, usually there are three ways, including restoring the ground temperature by UTES, taking an intermittent operation mode, and increasing the number of boreholes. As a consequence, the UTES technology can refresh and regenerate the initial ground temperature in a localized area for next repetitionary operation.

5.2. Function of control modes

In the recent research, it is found that while numerous efforts continue to improve heat transfer of UTES, fewer efforts have focused on the means of its operation mode control for seeking a better reuse efficiency. Therefore, authors presented new ideas, such as controllable heat diffusion, controllable load distribution, temperature field regeneration and thermal shield applied in the UTES for improving the efficiency greatly and facilitating application.

Table 3
Feature temperature increment.

Operational mode	Point A (°C)	Point B (°C)	Point C (°C)
Basic uniform mode	2.9	2.8	2.4
Concentrative mode	5.1	4.8	2.2
Intermittent mode	3.0	3.0	2.4
Heat shield mode	6.5	5.6	3.8

Based on the idea the researching work aims to investigate experimentally the heat transfer in the soil and rock for storing thermal energy and emphasizes to research the effect, temperature scope potential, ground temperature distribution and its variety. Four typical operational modes on the load of heat resources (boreholes of underground heat exchanger), such as uniform mode, concentrative mode, intermittent mode and heat shield mode were studied [59]. The test data of *Feature temperature increment in a experimental soil tank* are shown in Table 3. These feature temperature position in the soil tank were selected on the geometric center point A, the inside ring spacing point B and the outside ring spacing point C, respectively.

Comparing the four modes mentioned above, the heat shield mode can keep more energy stored in the limited area, mainly in the central area and its temperature is the highest on four modes after a same period (in the same total heat quantity and during same period). The behavior means that heat shield mode is a better way to get a high energy storage efficiency through the control of operational practice by the allotting the loads of each underground borehole exchangers. Such the control strategy can make well use of a subjective controlling and allotting the loads to reform and regenerate a configuration of ground temperature distribution for a high effect of UTES.

Thus, a new method of the higher conservation efficiency of TES in the soil/rock has been pursued by means of, respectively controlling every load of boreholes to enhance the practical maneuverability in UTES. The reformation of temperature distribution has been ideated and presented, and the behavior of heat shield has been found to realize a higher efficiency and establish an optimization way for UTES [60].

5.3. Practical preliminary experiment

Up to now in China, the idea of seasonal underground thermal energy storage in a SGCHPS for residential building and snow-melting on the road has been widely accepted under the driving force of the rapidly increasing applications of GSHP. It has been recognized as being among the cleanest, most energy-efficient and cost-effective systems for space heating and cooling, and other heat engineering. So some practical preliminary experiments will put into action gradually for promoting application of GSHP system with UTES.

For instance, the literature [48] described a detailed practical experiment of SGCHPS in 2008. Wang and Qi of Hebei University of technology studied the performance of underground thermal storage in a solar-ground coupled heat pump system for residential buildings. The results show that the performance of underground thermal storage of SGCHPS depends strongly on the intensity of solar radiation and the matching between the water tank volume and the area of solar collectors. Compared with the solar radiation, the variations of the water tank temperature and the ground temperature rise lag behind and keep several peaks during the daytime. For the case of Tianjin, the efficiency of underground thermal storage based on the total solar radiation and absorbed

solar energy by the collectors can reach over 40% and 70%, respectively. It is suggested that the reasonable ratio between the tank volume and the area of solar collectors should be in the appropriate range.

6. Further proposal of UTES R&D

As reported before, however, more efforts have been made to find out the means to serve energy storage as a vital and effective supplement. Up to now, much richer experiences of combined cooling and heating systems with soil/rock UTES or BTES as well as ordinary GSHPs in the practice have been reported very little. It is difficult to use GSHP profitably in the area of unbalanced heating/cooling load, such as the south and northeast of China. Certainly, some recent studies have begun to investigate the feasibility of using UTES. The investigation should be based on those studies by addressing the feasibility and possibility of a combined system of BTES and GSHP to provide a lowest power consumption and highest energy conversion efficiency.

As we reviewed the successful R&D in some countries of the world, the strategy plan will be proposed to China, which serves as the basic research work and the theoretical understanding for the first step, and the plan can guide the future and facilitate research, development, implementation and integration of UTES technologies that optimize energy utilization by improving overall energy efficiency and economic growth in heating and cooling of the building, while benefiting the local and global environment.

Actually, the development of GSHP and UTES need to be guided by the technology, promoted by the industry, led by the government and chosen by the market. It is important to study the experiences in advanced countries integrated with domestic own situation, innovate and promote its technology pilot projects, demonstrate with different types.

As we know, the BTES or soil/rock UTES technology involves complicated unsteady process, such as energy rejection, accumulation, preservation and extraction. First of all, some basic works on BTES should be more important due to much more boreholes as heat sources which compose and envelop a thermal field with complex heat transfer behaviors. Hence, as fundamental research problems, proposals for consultation are provided here for further application and development of BTES. They mainly contain,

1. Mechanism and characteristics of heat and mass transfer and the transient time-rate characteristic of UTES process, especially in each period of energy rejecting, accumulating, preserving and extracting should be explored.
2. Impacts of various conditions of complex geological structure, such as unsaturation, saturation, supersaturation and aquifer of geological stratification, underwater flow, porous, humidity shift and anisotropic heat transfer should be made clearly.
3. For a further identification of underground thermal properties, besides total heat conductivity, the thermal diffusivity, energy recovery factor, transient enthalpy distribution, energy density, energy variation intensity, etc. only for UTES will be investigated.
4. Some special thermal phenomena and behaviors, such as temperature gradient aberration, variance of moisture distribution and thermal capacity, heat hysteresis, and ice crystal forming and moisture shifting choke, should be studied.
5. Considering the practical application, numerous efforts will be made to explore the impact of cycle and time quota of storage energy (rejecting, accumulating, preserving and extracting) and seek an optimal actual effect in the cold and heat storage.
6. The control strategy for optimizing the energy storage system and improving efficiency will be emphasized, including most effective temperature distribution shape, load assignment and mass flow control in a multi-borehole field and thermal shield technology for the energy preservation.
7. The researching work mainly relies on the model analysis and computational simulation, and also will be based on the experiment investigation and validation, from the practical preliminary experiments, small engineering projects to the large-scale projects.

Based on the primary studies and investigations, some practical projects will be demonstrated gradually. Through the practice the utilization of UTES will be improved and promoted. It will implement an enabling technology for use in a variety of energy systems, from residential to commercial and from industrial to agricultural. By contributing to large-scale energy efficiencies, energy storage significantly reduces environmental impacts caused by energy activities, increases the potential uptake of some renewable energy technologies, increases the potential for sustainable energy development and subsequently leads to better energy security.

We are sure that the investigation of these problems will help for strengthening theoretical understanding, facilitating the progress of UTES and improving extensive application of GSHP in China and other countries.

7. Conclusion

ESTs are of strategic and necessary part for the efficient utilization of renewable energy and energy conservation. UTES is one form of ESTs and it is a valuable way to solve the problem of the imbalance between cooling load and heating load in some extreme hot or cold climate areas, especially in the north and south of China. The soil GSHP should be a potential mainstream for protecting groundwater.

As we known, the most aspects of UTES technology are companioning with the progress of GSHP in the field of using earth energy, so it will also promote GSHP technology. Especially, we should make more effect to the progress of BTES or soil/rock UTES. Further, the UTES system involves complicated unsteady processes that include energy rejection, accumulation, preservation and extraction. Therefore the basic issues were emphasized including the investigation of mechanisms, characteristics and performance of the unsteady and transient heat transfer in a complex underground environment, and control strategies of the UTES system. Anyway, the investigation of these problems will strengthen theoretical and practical understanding and facilitate more extensive application of UTES in China.

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